

OPTICAL FIBER COATING OPTIMIZATION TOOL FOR COMPOSITE EMBEDDED HEALTH MONITORING PURPOSES THROUGH A NOVEL TRANSFER MATRIX METHOD

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1. INTRODUCTION

With the increasing interest in structural health monitoring of composite structures, optical fiber sensors are receiving significant amounts of attention. Owing to their small size, chemical inertness, immunity to EM-interference... and fibrous nature make them ideal candidates as an embedded sensor in fiber reinforced polymers (FRP's). Although small, the diameter of an optical fiber (125 μm for traditional optical fibers) is still an order of magnitude larger than that of the reinforcing fibers (5 – 10 μm) and will therefore act as an inclusion in the material, affecting the strength of the final structure.

Researchers have already shown that depending on the load case and embedding location and orientation, significant decreases in strength can be detected in laboratory tests. In order to minimize these effects, other researchers have suggested that tuning the properties of the optical fiber coating material (added to increase handleability) might hold the key to decreasing these negative influences. Dasgupta et al [1] presented an analytical approach towards coating optimization for a purely axial load case in a unidirectional (UD) composite material. This method allowed the calculation of the stresses in the optical fiber, coating and composite material. Depending on the material properties of the FRP and coating, the stresses caused by embedding the optical fiber could be completely resolved using this method. Hadjiprociou et al [2] presented a finite element approach modelling an optical fiber in a UD laminate under transverse loads. An optimization criterion was presented allowing the determination of optimal coating properties in order to minimize the stresses in the composite material (and thereby the strength of the structure). In contrast to the axial load case studied by Dasgupta, completely resolving the stresses due to inclusion is generally not possible in this load case.

The studies performed by Dasgupta and Hadjiprociou provide very important information in order to minimize the influence of embedding an optical fiber in any FRP structure, and thereby increase the uptake in industry. However, both approaches offer only information for a single load-case, and in the case of Hadjiprociou requires multiple F.E. iterations in order to optimize the coating properties. This work presents a new methodology based on finite element analysis, allowing the user to quickly optimize the coating thickness for any type of load case within any type of lay-up (given certain boundary conditions on minimum layer thickness). The method finds the same optimal values as Dasgupta for axial loads and Hadjiprociou for transverse loads.

2. METHOD DESCRIPTION

The method proposed, uses a transfer matrix principle in which strains in the virgin material (ϵ) are related to strains at the coating-composite interface (ϵ') of the embedded sensor through a transfer matrix (T), which is a function of the location on the interface (described by the angle θ between a horizontal line and the line between the location at the interface and the center of the optical fiber). This is illustrated in Figure 1.

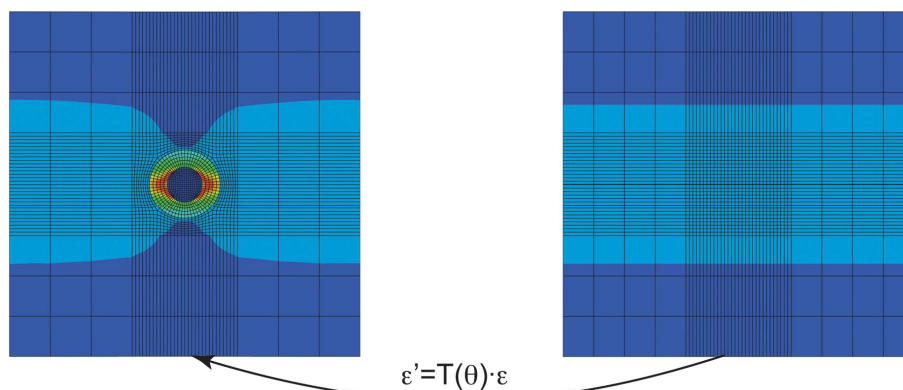


Figure 1. Principle of transfer matrix method

Since six independent strains exist in the virgin material, $T(\theta)$ should represent a 6x6 matrix and hence requires the simulation of six independent load cases to determine all necessary coefficients. However, by exploiting the transversely isotropic nature of the UD layer in which the OF is embedded, this can effectively be reduced to a 6x5 matrix since τ_{23} (1-axis representing the axial direction, 2-direction the in-plane transverse direction and 3-direction the out-of-plane direction) only results in a rotation around the fiber axis of the stress/strain field at the interface. Additionally, loading in the 2-direction results in interfacial stresses/strains identical to loading in the 3-direction, only rotated over 90° around the fiber axis. The same goes for shear in the 1-2 and 1-3 plane. This effectively reduces the number of independent simulations to three instead of six.

By performing the three independent simulations, the T-matrix can be calculated for all angles θ . Once the T-matrix is known, the interfacial stresses and strains can be calculated quickly for any load case. By calculating the T-matrix for material properties (coating thickness, coating material, host material...) an optimization can be performed.

3. PRELIMINARY RESULTS

Figure 2 compares the predictions made by the newly proposed transfer matrix method, to those predicted by Dasgupta (left) and Hadjiprocopiou (right). In both cases, the newly proposed method determines almost identical stresses as those presented by Dasgupta and Hadjiprocopiou respectively.

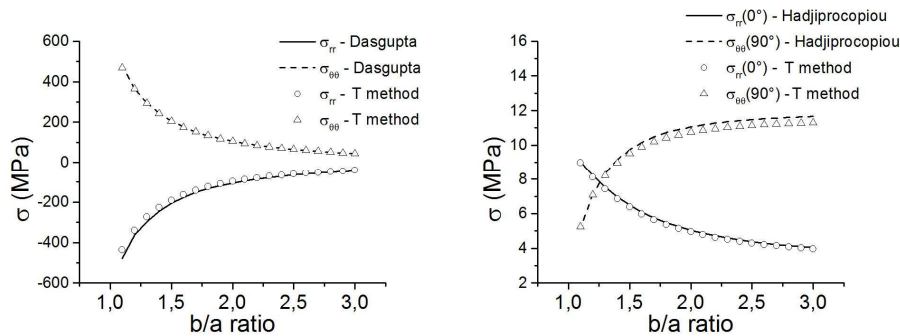


Figure 2. Comparison of newly proposed T-method, to Dasgupta (left) and Hadjiprocopiou (right)

In contrast to Dasgupta and Hadjiprocopiou however, the method is not limited to these two simple load cases but is capable of optimizing the coating for any type of load case (including time and spatial varying loads). While the initial effort of calculating the T-matrix might be more time consuming, the results can subsequently be used for any given load case. This might be of interest for industrial applications where many different structures (including different layups and load conditions) are created using only a couple of different FRP's. Under these circumstances, a database of T-matrices for different materials could provide all necessary information at a far lower cost (computational and time) as simulating every structure separately.

4. CONCLUSION

The newly proposed method allows the simulation and optimization of any load case. While the initial computational effort is higher than that of other methods, the subsequent time-saving can be significant in industrial applications where multiple structures or load cases have to be considered. Additionally, compared to methods proposed by Dasgupta and Hadjiprocopiou, this method provides information for any general load case, for which Dasgupta and Hadjiprocopiou provide no information. In case of perfect axial or transverse loads, the results of the transfer matrix method converge to those of Dasgupta and Hadjiprocopiou respectively.

ACKNOWLEDGEMENTS

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REFERENCES

- [1] Dasgupta A, Sirkis JS. IMPORTANCE OF COATINGS TO OPTICAL FIBER SENSORS EMBEDDED IN SMART STRUCTURES. Aiaa J. 1992;30(5):1337-43.
- [2] Hadjiprocopiou M, Reed GT, Holloway L, Thorne AM. Optimization of fibre coating properties for fiber optic smart structures. Smart Materials & Structures. 1996;5(4):441-8.